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The Marines' Ground-Attack Conventional Munitions Requirements Process

Ken Girardini

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**The Marines' Ground-Attack Conventional
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**Prepared for the
Assistant Secretary of Defense
(Production and Logistics)**

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PREFACE

This Note describes, evaluates, and suggests improvements to the Marines' conventional munitions acquisition process. The acquisition process is defined here to include the calculation of requirements and the imposition of budget and production constraints during procurement. The research is part of a study entitled, "Review and Improvement of Munitions Acquisition Processes," sponsored by the Assistant Secretary of Defense for Production and Logistics and carried out in the Acquisition and Support Policy Program in the National Defense Research Institute, RAND's federally funded research and development center supported by the Office of the Secretary of Defense and the Joint Chiefs of Staff.



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SUMMARY

This Note describes and suggests improvements to the requirement methodologies for ground-fired conventional ammunition developed for the U.S. Marine Corps (USMC). The analysis deals primarily with the shooter-oriented level-of-effort (SOLOE) and the target-oriented level-of-effort (TOLOE) methodologies. The SOLOE methodology is applied to mortars, grenades, and small-caliber munitions. The TOLOE methodology is applied to the anti-armor and artillery munitions. In both methodologies, the conflict is divided into six thirty-day periods and the ammunition requirements are output in rounds/tube/day for each period.

DESCRIPTION

In the SOLOE methodology, the USMC "plans sufficient stock to support reasonable amounts of fire from all viable weapon systems" and presumes there are sufficient targets to make such firing worthwhile. Hence, like most LOE methodologies, the SOLOE methodology focuses on the shooter population (in this case, Blue personnel). The Troop Population Model, a three-state Markov chain, tracks Blue personnel levels over time. Blue personnel receive reinforcements (a reconstitution) whenever further attrition would result in the population decreasing below a user input reconstitution level.

Unlike most LOE methodologies, the SOLOE methodology is insensitive to the attrition rate of the shooters. Because of reconstitutions, the number of Blue personnel remains relatively constant throughout the scenario. Therefore, Blue personnel casualty rates, though only one-seventh of the Army's estimates, do not significantly influence the requirement for SOLOE munitions.

The SOLOE methodology is most sensitive to the expenditure rates (input for each munition and each posture) and the posture profile (the sequence of combat postures that constitute the scenario). These inputs are estimated based on Marine professional judgment. Despite the considerable uncertainty in both the expenditure rates and the posture

profile estimates, no mechanism is included in the SOLOE methodology to examine the effects of uncertainty.

In a threat methodology, munition planners "plan to stock sufficient ammunition to defeat a specified threat" and presume there are sufficient shooters to do so. The TOLOE methodology is a hybrid between an LOE and a threat methodology because the target pool ("specified threat") is sized by tracking the attrition in the shooter population. The accumulated Blue personnel combat casualty rates (output from the Troop Population Model) and force exchange ratios (e.g., Red armor to Blue personnel) are used to determine the number of targets of each type defeated.

Targets are allocated among different weapon systems using a combination of Marine professional judgment and observations from Army ground-combat simulations. Target overlap among shooters is used to hedge against the uncertainty associated with allocating the targets to weapon systems. Based on the number of targets to be defeated and the probability of kill, the expected expenditures are calculated for each munition.

Because some shooters are expected to expend some of their initial allowance (IA) without resupply and end the conflict with less than a full IA of ammunition, the munition reserve required for resupply (resupply reserve) is less than the expected expenditures. The resupply reserve is calculated based on a Bose-Einstein distribution of munition expenditures among identical shooters. The resupply reserve is increased to ensure a statistical confidence level for the inventory exceeding expenditures of 99 percent. Logistic losses and zeroing (or registration) expenditures are also added to the resupply reserve. These calculations are performed in the Marine Threat Model.

The most critical inputs in the TOLOE methodology are the number of targets to be defeated (indirectly through the force exchange ratios and cumulative Blue personnel combat casualties), the allocation of the targets among the weapon systems, the rounds to kill, and the posture profile. For example, a lower Blue personnel combat casualty rate (again, lower than Army estimates) implies a smaller target pool and

results in a lower requirement for TOLOE munitions. Despite the considerable uncertainty in these inputs, no mechanism, other than increasing a single estimate of the demand (e.g., via confidence levels and target overlap), is included in the TOLOE methodology to examine the effects of uncertainty.

SUGGESTIONS FOR IMPROVEMENT

The current requirements process could be improved in several ways. These improvements are grouped into three categories: methodology, assumptions, and the treatment of uncertainty. Although comments on methodology are specific to the USMC process, the other two improvement categories apply to the other Services' requirements processes.

Methodology

Several methods for simplifying both the the SOLOE and TOLOE methodologies are discussed. Although the current process is not overly complex, the two most sophisticated aspects of the calculations, the Troop Population Model (three-state Markov chain) and the resupply portion of the Marine Threat Model (based on the Bose-Einstein distribution), could be removed without significantly affecting the final solution. The resulting calculations would be much simpler and transparent.

Assumptions

Several assumptions used in the requirements process could result in disconnects leading to poor procurement decisions. For example, through the Blue armor to Blue personnel attrition ratios, the Troop Population Model (whose inputs deal only with Blue personnel) establishes repair and replacement rates for major Blue weapon systems. The resulting requirements may be for Blue weapon systems that could not be fielded in the desired time frame. As another example, the assumption of unconstrained ammunition logistics can result in consumption rates far exceeding the capacity of the logistic system.

The problems described above are the result of the "compartmentalization" of the requirement and procurement processes for munitions and related assets (distribution). Munition requirements are typically devoid of the constraints imposed by budgets, production, and logistics. Completely ignoring the constraints degrades the value of the information generated by the requirements process and increases the risks of serious imbalances between related areas (e.g., stocks and the distribution system). Rather, a simpler and more responsive methodology could be run several times, allowing decisionmakers to examine the trade-offs of different investments.

Treatment of Uncertainty

The **two most** important criticisms are (1) the use of a single scenario to calculate the requirement (i.e., incomplete treatment of the sources of uncertainty) and (2) concealing the effects of uncertainty from decisionmakers by increasing a single estimate of the requirement (i.e., provides no additional information for decisionmakers). These problems are interrelated and must be dealt with simultaneously to improve the process.

The current requirements process accounts for uncertainty by using a **single** "worst case" scenario, target overlap, and high confidence levels for statistical uncertainty. However, the USMC must be concerned with the full range of uncertainty that cannot be captured appropriately in a single scenario. For example:

- The Marines' charter is to be prepared to engage on a worldwide basis. How can the analysis of a single scenario for ammunition planning conceivably be sufficient to fulfill the USMC's charter?
- Target overlap is used in the allocation of targets to weapon systems in the TOLOE methodology. What about target overlap with the Army and our allies?

- The statistical variability for a given estimate of the mean probability of kill (pK) is accounted for at a confidence level of 99 percent (e.g., the number of coin tosses required to produce 50 heads with 99 percent confidence). The considerable real world uncertainty associated with weapon system performance, however, is ignored (e.g., the fairness of the coin).

A single estimate of the requirement conceals the effects of uncertainty from decisionmakers. It suggests that "buying out" the uncertainty in the form of larger inventories is the only option. However, the "buy out" option may **not** provide the most robust or cost effective solution to the problem.

The above problem is only magnified in a resource-constrained environment. If it is not possible to fund the entire requirement, then the safety stocks associated with uncertainty may never be procured. Furthermore, inflating the single estimate conceals information from decisionmakers. For example, target overlap is one method used to account for uncertainty. Decisionmakers may unknowingly buy out the uncertainty in one munition without meeting the nonoverlapped target threat for another munition.

Making procurement decisions based on a single estimate increases the risk of large differences existing between the projected ammunition consumption rates used for planning and procurement and the rates encountered in an actual contingency. Because resources are constrained, decisionmakers require information on the different demands that might occur to plan a robust combination of inventories and production capacity (and a logistic system capable of supplying munitions to the shooters). The additional information would be best provided by a simpler and more responsive methodology that could be executed for several scenarios and allow decisionmakers to investigate the trade-offs associated with different investment options.

ACKNOWLEDGMENTS

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ABBREVIATIONS

ADAM	Artillery delivered anti-personnel mine
AIHQ	Ammunition initial issue quantity
AMCCOM	Armament, Munitions, and Chemical Command
AP	Armor piercing
AT	Attack (posture)
ATCAL	Attrition Calibration model
CAA	Concepts Analysis Agency
CAS	Close air support
COSAGE	Combat Sample Generator
DE	Delay (posture)
DG	Defense Guidance
ETD	Equivalent threat division
FASCAM	Family of scatterable mines
HE	High explosive
HEAA	High-explosive, antiaircraft
HMMWV	High-mobility multipurpose wheeled vehicle
ICM	Improved conventional munition
ID	Intensive defense (posture)
K-kill	Catastrophic or total kill
K-V	Killer-victim
LAV	Light armored vehicle
LD	Light defense (posture)
LOE	Level of effort
MEF	Marine expeditionary force
OSD	Office of the Secretary of Defense
pK	Probability of kill
PPBES	Programming, planning, budgeting, and execution system
POM	Program Objective Memorandum
RAAM	Remote anti-armor mine
SMAW	Shoulder-launched multipurpose assault weapon

- xx -

TOW Tube launched, optically tracked, wire guided
WR War reserve

I. INTRODUCTION

This Note describes and evaluates the methodology, documented as the 1987 Class V(W) study [1], used in calculating the United States Marine Corps' (USMC's) war reserve (WR) requirement for ground-launched¹ munitions. The Defense Guidance (DG) defines the WR requirement as the quantity of munitions that must be produced in peacetime and stored in inventory to satisfy the wartime demand until the DoD materiel distribution system is able to sustain combat consumption.

The methodology described was *not approved* by the USMC, so the most recent USMC WR requirement was calculated using the 1982 Class V(W) study [2]. Use of the 1987 Class V(W) study was limited to munitions not included in the 1982 study (e.g., munitions recently introduced into the force structure).

The major components of the current methodology were first introduced in the 1981 Class V(W) study [3]. The methodology of the 1987 study encompasses all the components of the previous USMC Class V(W) studies (the results of which were approved by the USMC). Because the 1987 methodology was not approved by the USMC, however, the major differences between the methodologies of the 1987 study and the previous studies are described.

Generation of requirements² is the initial step of the Planning, Programming, Budgeting, and Execution System (PPBES). An *unfunded requirement* is the requirement minus current inventories. A goal of the programming process, the next step of the PPBES, is to allocate resources to fill unfunded requirements over the five-year horizon of the Program Objective Memorandum (POM).

¹The munition consumption rates for the Marine Air Wing are calculated by the Navy in the Non-Nuclear Ordnance Requirement (NNOR) process. Budgeting for these munitions also falls within the Navy's appropriations.

²The overall requirement for munitions is the sum of the WR requirement and the peacetime losses over the five-year planning horizon of the POM. The calculation of peacetime losses (e.g., training and testing of inventories) is not discussed.

Estimating requirements for ground-launched munitions is the responsibility of the Commanding General, Marine Corp Combat Development Command. The responsible office is the Warfighting Center (CODE WF-11G). The methodology for the 1987 Class V(W) study was developed, executed, and documented by a contractor. Additional analytical support is received from the Marine Corps Operations Analysis Group.

The DG (issued by OSD to all the Services) establishes many of the assumptions used in a Class V(W) study. Expenditures are assumed unconstrained by munition logistic capacity, budget resources, existing production capacities, or existing munition inventories.

The DG also provides an outline of the contingency, the time frame, duration of the contingency, warning times, broad strategic goals, and so forth. The USMC, however, does not relate its conventional munition requirements directly to the scenario outlined in the DG. Rather, the planning is focused on a more microcosmic situation involving a single Marine Expeditionary Force (MEF, or USMC division) launching an amphibious assault tailored to some aspect of the DG. The USMC uses a portfolio of standard assault scenarios, referred to as the MARCOR (Marine Corps) series, to help ensure consistency among its various munitions, weapon systems, logistics, and training programs.

Because the USMC's mission is to be ready for combat deployment anywhere in the world, numerous assault scenarios could be used in a Class V(W) study. To hedge against uncertainty, the MARCOR-1B scenario (Marine Corps scenario 1B) used in the 1987 Class V(W) study provides a "reasonable worst case" for munition consumption. The MARCOR-1B scenario involves a NATO-oriented MEF fighting at an intensity level associated with a high munition expenditure region.

The MARCOR-1B scenario is described as a single reinforced MEF in a series of 180 posture days (referred to as a *posture profile*). The idea of a combat posture day is one of several concepts borrowed from the Army. For example, the establishment of a beachhead is described as a series of attack days, an enemy counter attack to recapture the beachhead as a series of intensive defense days, and so on. The posture profile is a critical input for the methodologies used in a Class V(W) study.

The results of the Class V(W) study, referred to as Class V(W) *planning factors*, are expressed in rounds/day/initially deployed weapon system. The Class V(W) study is executed for a single (reinforced) MEF, but the planning factors are multiplied by the authorized (initially deployed) weapon system densities of the USMC's three active and one reserve MEFs.

The total inventory objective for munitions includes the WR requirement described above, allowances for special mission forces, general support, mobilization training, and losses in shipping to the combat zone. Priorities are formulated by the USMC to determine how to allocate resources to the unfunded requirement while satisfying real world constraints (e.g., limited budget resources and production capacities).

The methodologies used in the 1987 Class V(W) study, typical weapon systems and their munitions, typical targets, and their percentages of the 1987 munition budget³ are listed in Table 1. To determine the appropriate methodology, munition types are matched to the assumptions of the methodologies.

In this Note, we describe the shooter-oriented level-of-effort (SOLOE) and target-oriented level-of-effort (TOLOE) methodologies. The former is described in Sec. II and the latter in Sec. III. Section IV contains an evaluation of both methodologies.

The air threat allocated to USMC threat munitions will be determined by OSD. Given the target population, the threat methodology is identical to the TOLOE methodology.

Special methodologies based on mission-related doctrine and tactics are used to estimate the combat planning factors for mine,⁴ countermine, smoke, and illumination. The number of missions and the expenditures per munition are based on Marine professional judgment. These methodologies are not described further here.

³Because acquisitions in any given year are affected by previous outlays, total inventory value or procurement over the last five years would provide a better estimate of the economic impact of the methodologies.

⁴Rates for artillery delivered mines (i.e., FASCAM) are calculated in the TOLOE methodology.

Table 1

CLASSIFICATION BY METHODOLOGY

Methodology	Weapon System or Munition	Typical Target	Percent of 1987 Budget
TOLOE	TOW, DRAGON, tank & LAV guns, artillery, SMAW, AT-4	Armor, artillery, field fortifications, buildings, command posts	41.4
SOLOE	Mortars, grenades, small caliber, signal devices	Personnel, lightly armored vehicles	32.4
Threat	STINGER, HAWK	Fixed-wing aircraft, helicopters, antiradiation missiles	21.7
Special	Artillery-delivered smoke and illumination	None	1-3
	Countermines	Mines	
	Mines	Armor and personnel	

II. SHOOTER-ORIENTED LEVEL-OF-EFFORT (SOLOE) METHODOLOGY

In the SOLOE methodology, the USMC "plans sufficient stock to support reasonable amounts of fire from all viable weapon systems" and presumes there are sufficient targets to make such firing worthwhile.¹ This allows munition planners to focus on the shooter population.

Figure 1 is an overview of the SOLOE methodology. The shooter population for all of the SOLOE munitions is Blue personnel. The Troop Population Model (TPM), a one-sided personnel inventory model based on a three-state Markov process, tracks the Blue personnel population. The rate of consumption per hour per combat active Marine, established using Marine professional judgment, is the most critical input to the SOLOE methodology. The expenditure rates are also influenced by fluctuations in the number of combat active Blue personnel (output from the TPM), initial allowances for weapon systems, logistic losses, and expenditures for zeroing weapon systems.

THE TROOP POPULATION MODEL

The TPM, labeled "USMC SHOOTER POPULATION" in Fig. 1, is a Markov chain model of Blue personnel with three states: combat active (CA), temporarily inactive (TI), and no longer active (NLA). CA personnel are capable of engaging the enemy. TI personnel have nonzero probability of returning to the CA state during the conflict. NLA personnel cannot return to the CA state during the conflict. The TPM tracks Blue personnel on a daily basis by multiplying the number of Marines in each state by a (Blue personnel) transition matrix.

The conflict is represented in the TPM as a series of posture days (posture profile). There are four postures: intensive defense (ID), attack (AT), delay (DE), and light defense (LD). Each posture represents specific Red to Blue force ratios, tactics, and doctrine.

¹Equivalent to the assumptions (1) shooters do not run out of targets and (2) the expenditure rates are not a function of the number of remaining targets.

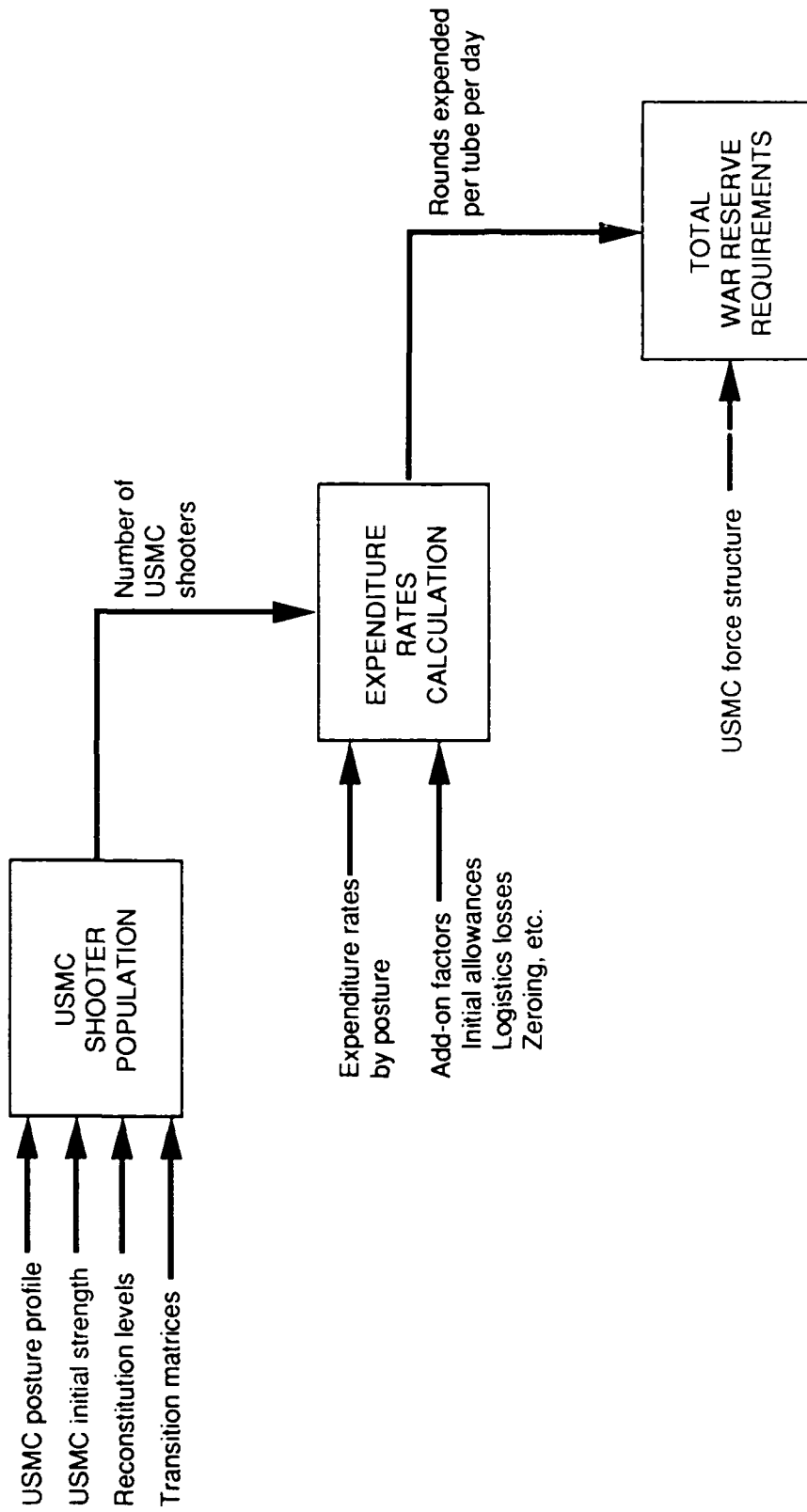


Fig. 1—Overview of the SOLOE methodology

The combat casualty rate (for Blue personnel) varies with posture, so a different transition matrix is calculated for each posture. A special transition matrix is used on D-day to represent in-transit losses.

Each transition matrix has the form below:

	NLA	TI	CA
NLA	1	0	0
TI	a	1-a-b	b
CA	c	d	1-c-d

The entry in row x and column y represents the probability of a Marine changing from state x to state y in a day. The combat casualty rate, the noncombat casualty rate, and the split of casualties between TI and NLA define c and d. The values a and b are defined by the average number of days a Marine remains TI and the percentage split of Marines exiting the TI state between CA and NLA.

The combat casualty rates for each posture are the most difficult inputs to estimate. The other inputs to the transition matrix are independent of posture and are estimated from historical data. Hence, only the third row differs in the five transition matrices associated with the four postures and D-day.

The combat casualty rates for each posture are estimated using Marine professional judgment. The USMC's estimates of the personnel combat casualty rates are only one-seventh of those predicted by the Army.² Although there are differences in the combat envisioned by USMC and Army commanders, the magnitude of the gap between casualty rates implies there is considerable uncertainty associated with combat casualty rates for given scenarios and postures.³

²The combat casualty rate used by the Army is an output of the Combat Sample Generator (COSAGE) model. COSAGE is a division-level, two-sided, combat simulation model.

³The effect of this difference on both the SOLOE and TOLOE munition requirements is discussed at the end of Sec. II and Sec. III, respectively.

The *cumulative* number of Marines passing through the TI state or permanently in the NLA state increases each day (see Fig. 2) and represents the cumulative Blue personnel casualties. To ensure the number of Marines in the CA state does not fall below a specified percentage of full strength, a reconstitution level is input (dashed line in Fig. 3). When the number of CA Marines decreases to the reconstitution level, a reconstitution (i.e., reinforcement) instantaneously increases the number of combat active Marines to full strength. For example, there are reconstitutions at days 60 and 120 in Fig. 3. The number of reconstitutions is most strongly influenced by the reconstitution level and the combat casualty rates.

The availability of the resources required to carry out reconstitutions (e.g., reinforcement personnel) is not addressed in the Class V(W) study. It is not clear if the reconstitution level and combat casualty rates are adjusted to achieve a feasible level of

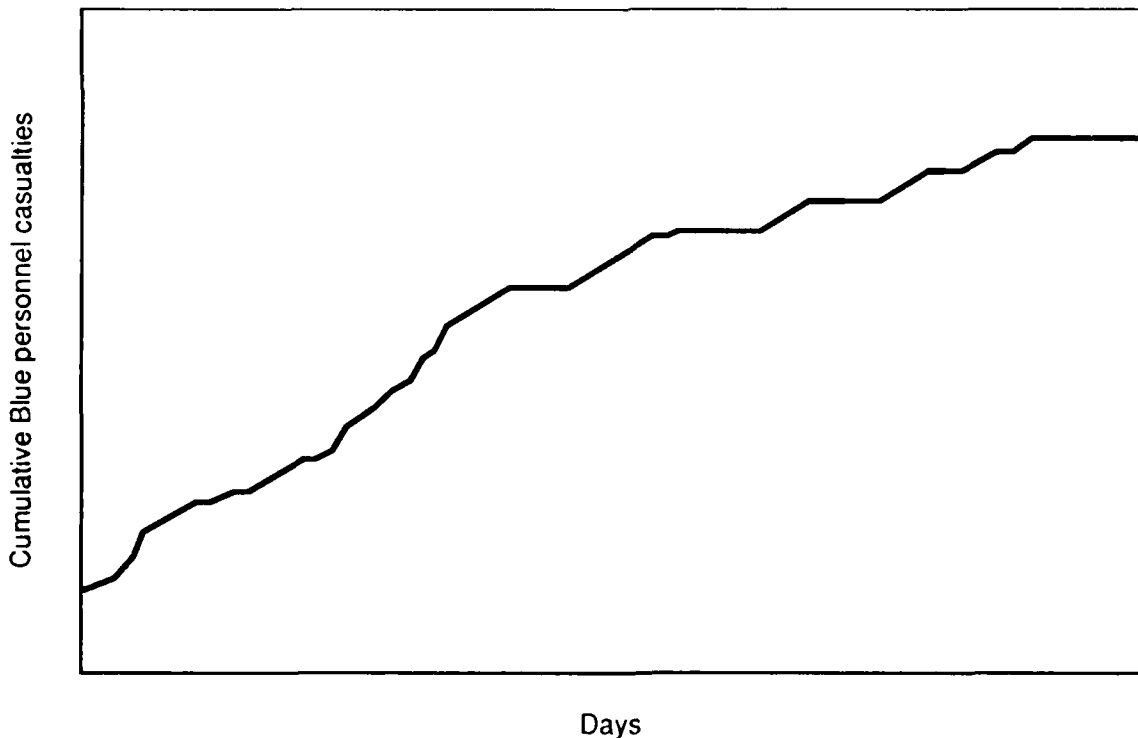


Fig. 2—Output of the TPM: cumulative Blue combat casualties

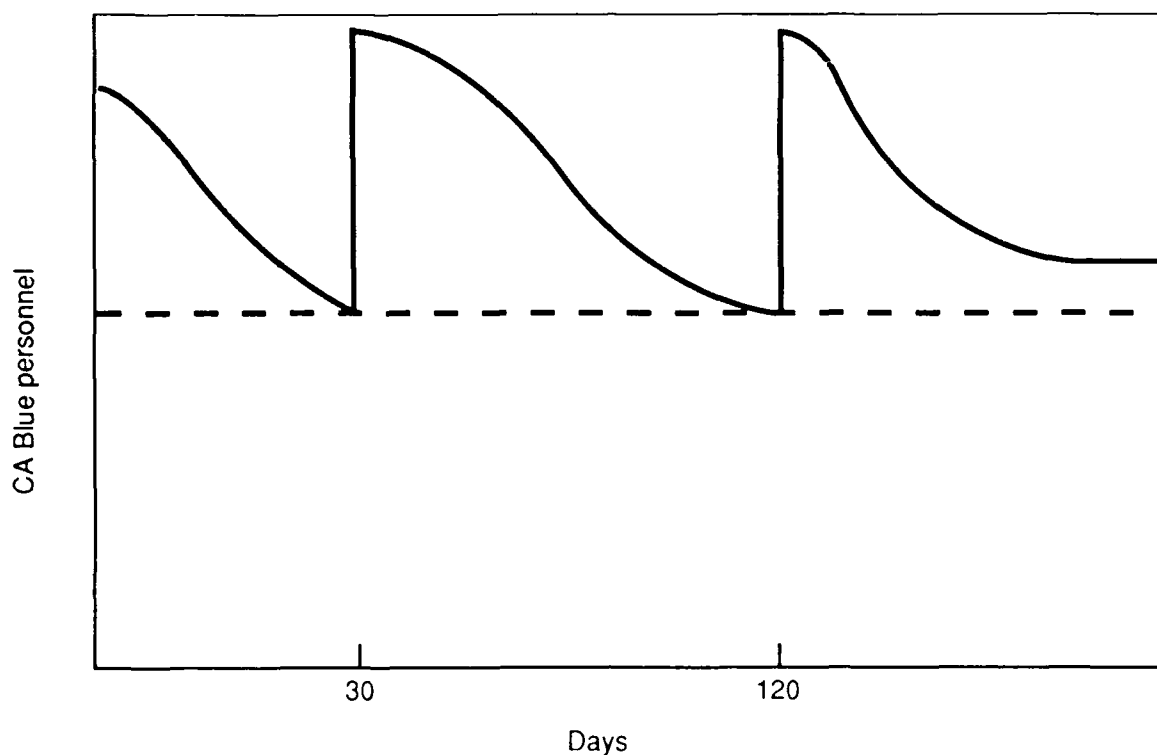


Fig. 3—Output of the TPM: number of combat active Blue personnel

reinforcement for a 180 day scenario or if the availability of reinforcements is assumed.⁴

In reality, the casualty rates would vary every day regardless of the posture. No attempt, however, is made to model the day-to-day variations. The TPM uses the expected value inputs to provide expected value outputs.

The number of combat active Marines is an input to the SOLOE calculations. Also, the number of cumulative combat casualties output from the TPM is an input to the TOLOE methodology (labeled "USMC casualties" in Fig. 4, Sec. III).

⁴Although the scenario involves just one (reinforced) MEF, the expenditure rates are multiplied by the weapon system densities of each of the USMC's MEFs in calculating the final requirement.

CALCULATION OF THE RATES

The most important input to the SOLOE methodology is the number of rounds expended per committed shooter per hour in the ID posture. This input is estimated for each SOLOE munition using Marine professional judgment. Estimates of the expenditures in the other postures relative to the ID posture and the number of hours of combat in a day are used to extrapolate the single estimate of rounds/*hour*/shooter for ID to rounds/*day*/shooter for each posture.

The scenario is broken into six thirty-day periods. The next step is to average the posture specific expenditure rates over the posture profile, include expenditures not associated with rounds fired in anger, and calculate the effects of shooter attrition (i.e., the results of the TPM). For a given day, the number of combat active Marines⁵ (output from the TPM) is multiplied by the rounds/day/shooter associated with the appropriate posture. The expenditures for each day of a thirty-day period are summed. Initial allowances for initially deployed weapon systems (Blue personnel), initial allowances for destroyed weapon systems,⁶ and rounds used for weapon systems zeroing are added to expenditures. The total munition consumption for each period is multiplied by a factor to account for logistic losses. The combat planning factors for each period are expressed in rounds/day/initially deployed shooter.

⁵The calculations proceed as though every Marine is equipped with each SOLOE weapon system (e.g., every Marine has a rifle, pistol, shotgun, machine gun, mortar, etc.). Because the number of Blue personnel eventually appears in both the numerator and denominator, whether every Marine has each SOLOE weapon system or a given percentage has each SOLOE weapon system makes no difference in the calculation.

⁶Blue personnel casualties result in the destruction of the weapon system and its initial allowance of ammunition. All weapon systems destroyed in a period are assumed replaced in the same period and require an initial allowance on redeployment. Hence, the number of weapon systems destroyed in combat is directly proportional to the personnel casualties. For example, if the personnel casualty rate is 15 percent, then 15 percent of the mortars, machine guns, rifles, etc. are destroyed.

The consumption of SOLOE munitions for each period is calculated by multiplying the number of personnel in the USMC's three active and one reserve MEFs by the combat planning factors for each period and the number of days in each period (30). Because the combat planning factors change from period to period, the requirement is expressed as a function of time (e.g., more intense combat, and hence, greater munition consumption in the first period of the conflict). The total WR requirement is the sum of the consumption for the six periods.

Counter to the usual LOE logic,⁷ the shooter attrition rate does not significantly affect the requirement. Because the reconstitution level removes the possibility of large decreases in the shooter population,⁸ the lower combat casualty rates used by the USMC (one-seventh of those predicted by the Army) have only a minimal effect on the estimate of the requirement for SOLOE munitions.

The results of the SOLOE methodology depend almost entirely upon the estimate (for each munition) of the expenditure rate in rounds/tube/day for each posture and the posture profile, and there is considerable uncertainty associated with both inputs. For example, if several knowledgeable individuals estimated the expenditure rate for a given munition, there would probably be substantial differences among the estimates. The posture profile and, ultimately, the estimates of the expenditure rates are based on a specific scenario. The USMC's mission as the nation's force in readiness suggests there are numerous valid scenarios. The SOLOE methodology does not include mechanisms for dealing with these uncertainties.

⁷The assumptions used in an LOE methodology allow the analyst to focus on the shooter population.

⁸The number of combat active Blue personnel is between the initially deployed strength and the reconstitution level throughout the scenario (see Fig. 3).

III. TARGET-ORIENTED LEVEL-OF-EFFORT (TOLOE) METHODOLOGY

The TOLOE methodology is a hybrid between an LOE and a threat methodology. In a threat methodology, munition planners "plan to stock sufficient ammunition to defeat a specified threat" and presume there are sufficient shooters to do so. Because the environment is assumed target limited, a threat methodology allows the analyst to focus on the target population. In the hybrid TOLOE methodology, however, both the shooter and target populations are tracked.

As illustrated in Fig. 4, the Blue personnel combat casualties output from the TPM (labeled "USMC casualties" in Fig. 4) and the force exchange ratios determine the number of targets of each type ("TARGET POOL").¹ Once the number of targets to be defeated is known, they are allocated among the different types of weapon systems ("THREAT SPLIT"). Once a weapon system is assigned a fixed number of targets, a specific round type is assigned (i.e., some weapon systems fire more than one type of munition). The number of rounds required to defeat each type of target (i.e., $1/pK$) multiplied by the number of targets of each type yields the expected expenditures ("EXPECTED EXPENDITURES"). The calculations associated with the final two tasks in Fig. 4, expected reserve and total war reserve requirement (described in subsection "Marine Threat Model"), include the effects of munition resupply policy (but not logistics), initial allowances for weapon systems, statistical uncertainty, and additive factors. The projected expenditure rate is output in rounds/day/initially deployed weapon system for each munition-period combination.

¹Titles in parentheses refer to Fig. 4 and to subsections below that describe the calculations. For complicated calculations, the subsections may be further divided with subheadings.

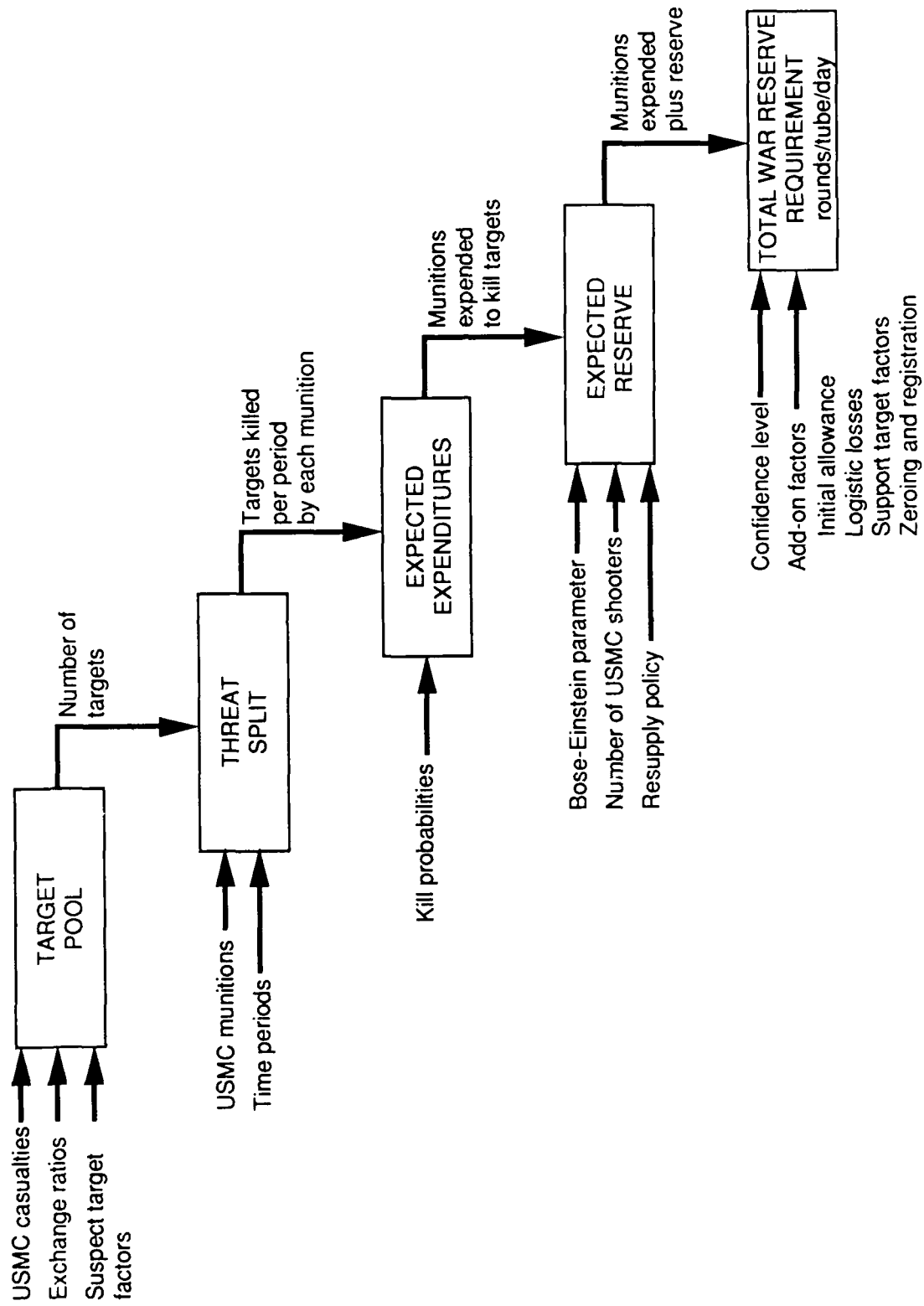


Fig. 4— Overview of the TOLOE methodology

THE TARGET POOL

The initial task of the TOLOE methodology is to calculate the number of targets in each threat category (tanks, armored personnel carriers, major indirect-fire weapons, field fortifications, buildings, and command posts) that a reinforced MEF² should defeat (referred to as the "target pool"). In previous Class V(W) studies, the target pool for armor and artillery was estimated (in a single step) using Marine professional judgment. Figure 5 is an illustration of the methodology used in the 1987 Class V(W) study to calculate the armor and artillery target pools and is explained in detail in the subsections below. The methodology for estimating the target pools for field fortifications, buildings, and command posts has not changed and is based on the posture profile (number of attack days), estimates of the number of targets, and estimates of the rate of reconstitution of destroyed targets.

The Threat Forces

The threat force is taken from the MARCOR-1B scenario. However, the weapon effectiveness indices/weighted unit values (WEI/WUV)³ score of the initially deployed threat exceeded the WEI/WUV score of a Marine Expeditionary Force. Hence, an equivalent threat division (ETD)⁴ with a WEI/WUV score approximately equal to the score of an MEF is used to define the force ratios associated with different combat postures.

A scenario involving the MEF and ETD(s) is described as a series of 180 days with each day in one of the following postures: attack (AT), light defense (LD), delay (DE), or intense defense (ID). Each of the postures is associated with a force ratio expressed in terms of an ETD and an MEF. The Blue to Red force ratios are: 1 MEF to 1/2 ETD in attack, 1 MEF to 1 ETD in light defense, 1 MEF to 2 ETDs in intense defense, and 1 MEF to 3 ETDs in delay.⁵ The force ratios are defined in terms of combat worth (not ratios of actual divisions).

²The level of reinforcement required to maintain an MEF at acceptable levels is determined in the TPM (see Sec. II).

³WEI/WUVs are a static measure of combat potential developed, but no longer accepted, by the Army.

⁴The ETD consists of major weapon systems in the same proportions as the initially deployed threat in the MARCOR-1B scenario.

⁵The postures are defined as one MEF engaging different multiples

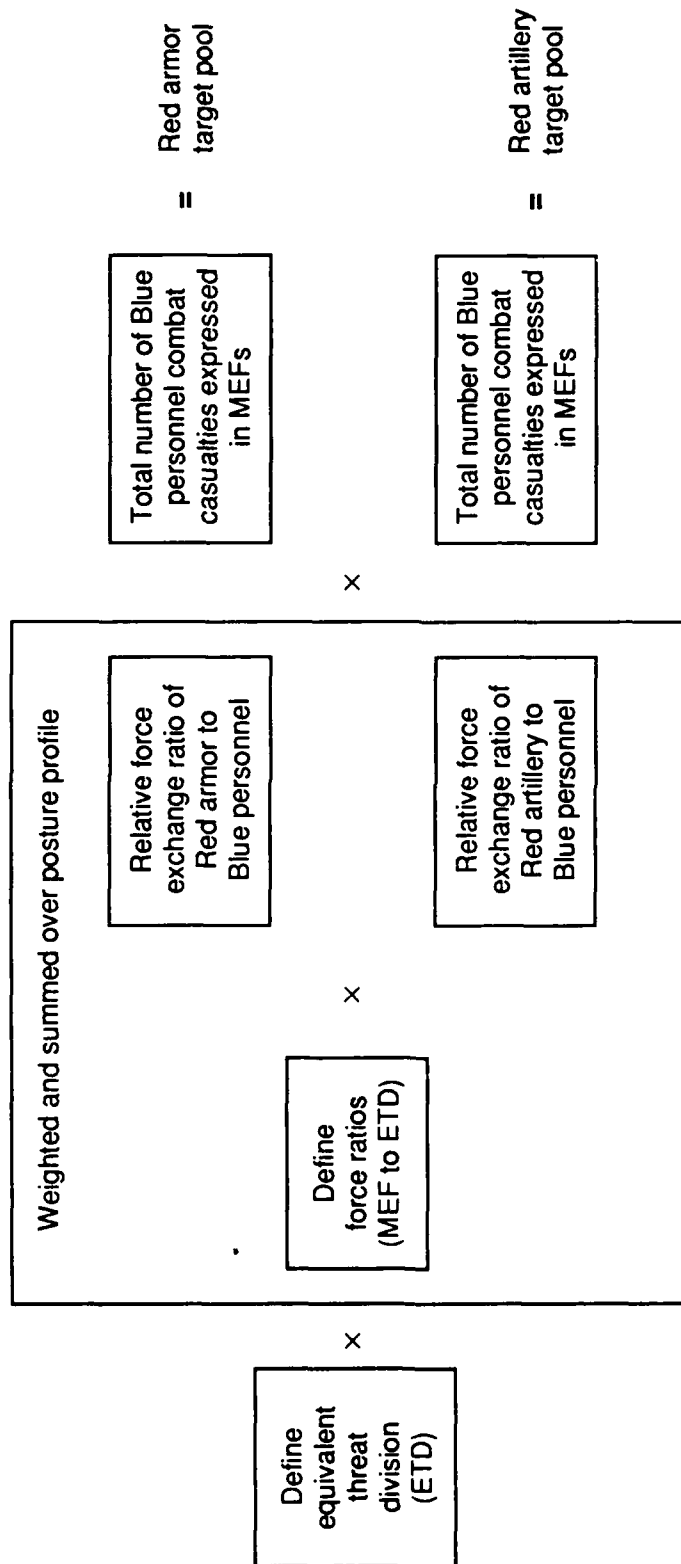


Fig. 5—Calculation of armor and artillery target pools

By defining the ETD, force ratios associated with the four postures, and the posture profile, the threat to be faced by the reinforced MEF throughout the scenario is known.

In the TOLOE methodology, unlike most threat methodologies, the armor and artillery target pools are not assumed equal to the the number of targets of each type to be faced, as if all the targets must be defeated. Rather, the target pool is calculated by accumulating the percentage of the threat defeated each day. The calculation starts with a known threat and determines the target pool in two steps. First, *relative* force exchange ratios, stated as a function of percent Blue personnel combat casualties, are estimated. In the second step, the force exchange ratios are multiplied by the cumulative Blue personnel combat casualties output from the TPM and the number of targets of each type in an ETD to get the number of targets defeated. These steps are described in the next two subsections. Finally, in the third subsection, comments are made on the overall process of determining the target pool.

Relative Force Exchange Ratios

Table 2 provides an example, based on fictitious values, of the calculation described above. The ratio of percent Blue armor attrition to percent Blue personnel combat casualties is established for each posture (A).⁶ Similarly, Red armor to Blue armor percent attrition ratios are established for each posture (B). Each posture is defined in terms of one MEF against different multiples of an ETD (C). The relative ratio of percent Red armor attrition to percent Blue personnel casualties (D), in terms of the assets of a single ETD, is calculated by multiplying lines A, B, and C of Table 2. The ratios for each posture are averaged over the posture profile (E) to determine the Red armor to Blue personnel relative force exchange ratio (H). Finally, the estimated ratio of percent Red artillery attrition to percent Red armor

of ETDs. The MEF, however, is not engaged for 24 hours a day for the entire 180 day scenario. Historically, the USMC has associated less than 24 hours of active combat with the postures.

⁶See the line labeled (A) in Table 2.

Table 2

RELATIVE FORCE EXCHANGE RATIOS

Item	AT	LD	ID	DE
(A) Percent losses Blue armor/Blue personnel	4/1.5	0.6/0.3	4/3	4/3
(B) Percent losses Red armor/Blue armor	8/4	1.5/0.6	8/4	8/4
(C) Number of ETDs vs. 1 MEF	0.5	1.0	2.0	3.0
(D) Percent losses Red armor/Blue personnel	4/1.5	1.5/0.3	16/3	24/3
(E) Days in posture (posture profile)	30	125	20	5
(F) Overall ratio Blue armor/Blue pers = $295/157.5 = 1.87/1$				
(G) Overall ratio Blue artillery/Blue pers = $1.22/1$ (60% of armor)				
(H) Overall ratio Red armor/Blue pers = $747.5/157.5 = 4.75/1$				
(I) Overall ratio Red artillery/Blue pers = $2.85/1$ (60% of armor)				
(J) Blue personnel combat casualties per 1000	15	3	30	30

attrition (0.6) times the Red armor to Blue personnel relative force exchange ratio equals the Red artillery to Blue personnel relative force exchange ratio (I).

With the results of the Army's Combat Sample Generator (COSAGE) as a point of reference,⁷ the ratios in lines A and B of Table 2 are estimated using Marine professional judgment. The technique of observing COSAGE results by posture, correcting each posture for service differences using Marine professional judgment, and averaging the results over the posture profile of the USMC scenario is used several times in the TOLOE methodology. It will be referred to as the *COSAGE-Marine-posture* technique. The ratios from COSAGE, not the values of the numerator and denominator, are used in the *COSAGE-Marine-posture* technique (e.g., 14/28 and 2/4 are both equal to 1/2).

⁷COSAGE is a division-level, two-sided, combat simulation used by the Army to evaluate combat results for a 24-hour period in each of the four postures (AT, ID, LD, and DE).

The percentage of Blue personnel combat casualties (line J and the denominator in lines A and D of Table 2) is the Blue personnel combat casualty rate input to the TPM. As stated in Sec. II, the Blue personnel combat casualty rate used by the USMC is significantly lower (approximately one-seventh averaged over the USMC posture profile) than the casualty rates output from COSAGE. Therefore, to achieve the same relative ratio, the Red and Blue armor attrition rates are approximately one-seventh the values output from COSAGE (numerators in lines A and B). Lowering the Blue personnel combat casualty rates while holding the force exchange ratios (essentially) constant decreases the intensity of combat associated with a given posture day and, hence, the requirement for all TOLOE munitions by a factor of 7. The difference between Army and USMC estimates is discussed further in Sec. IV.

Because it is impossible to simulate in detail every division-level engagement in a theater conflict, COSAGE is based on notional Red and Blue divisions. The force structure of a notional division is chosen to be representative of the weapon systems employed in the Army's theater-level model. The notional divisions do not represent actual Red or Blue divisions (e.g., an MEF or ETD). As part of a hierarchical structure, the Army uses the Attrition Calibration Model (ATCAL) to correct for changes in force structure when evaluating the combat outcomes of engagements in the theater model (engagements between actual divisions altered by attrition and resupply). The force exchange ratios for TOLOE munitions could be estimated by using ATCAL equations (for each posture) to evaluate the attrition associated with a day of combat between an MEF and (a posture dependent multiple) of an ETD. Because the relative force exchange ratios are a strong function of the force structure, this would provide a better reference point. Differences in tactics and doctrine would still be corrected using Marine professional judgment.

Conversion from Relative to Absolute

Given the Red and Blue force strengths over the duration of the scenario and the relative force exchange ratios, it is possible to define the target pools for Red armor and artillery. The cumulative Blue personnel combat casualties, output from the TPM, is expressed in multiples of an MEF and multiplied by the overall Red armor and artillery ratios (lines H and I of Table 2). The result is the equivalent threat divisions of armor and artillery defeated by a reinforced MEF.

For example, an upper bound on cumulative Blue personnel combat casualties can be calculated by multiplying the Blue casualty rate by the posture profile ($30 \times 1.5\% + 125 \times 0.3\% + 20 \times 3\% + 5 \times 3\% = 157.5\%$). Because less than a full MEF may be engaged due to attrition before a reconstitution, cumulative Blue personnel casualties are approximated as 1.4 MEF (140 percent of an MEF).⁸ Blue casualties of 1.4 MEF multiplied by the Red armor ratio of 4.75 results in 6.7 ETDs. Hence, the Red armor target pool consists of the armor assets (tanks and armored personnel carriers) of 6.7 ETDs. Similarly, the Red artillery target pool consists of the artillery assets of 3.0 ETDs. Recall, these numbers represent the number of targets to be defeated by a *single* reinforced MEF.

Comments

In the 1982 Class V(W) study, the target pool was estimated directly using Marine professional judgment (the usual threat-based methodology). The TOLOE methodology uses a far more complex and confusing process involving WEI/WUVs, force exchange ratios, and the like to estimate the target pool. The methodology is classified as LOE

⁸The cumulative combat casualties output from the TPM can be replaced by the the combat attrition rate per posture multiplied by the number of days in each posture (summed over the posture profile). Because the Blue personnel population must be between a full MEF and the reconstitution level (see Fig. 3), a more accurate estimate of the TPM output is calculated by multiplying the above result by .XX MEF (.XX equals $[1 + \text{the reconstitution level represented as a fraction}]$ divided by two).

to be consistent with the DG.⁹ Hence, once the target pool has been estimated, the TOLOE methodology is identical to the threat-based approach used in 1982.¹⁰

Threat-based methodologies are criticized because the calculations are not affected by shooter attrition. Shooter attrition is of interest for two reasons: (1) to ensure there are enough shooters to defeat the targets and (2) to affect the magnitude and timing of the requirement. The TOLOE methodology, initially, appears to improve both of these deficiencies because it tracks both the shooter and target populations and shooter attrition does affect the magnitude and timing of the requirement. But, this is accomplished through a tenuous relationship with the accumulated Blue personnel combat casualties output from the TPM.

That sufficient shooters would, in reality, exist to defeat the target pool is not immediately obvious. Reconstitutions of Blue personnel in the TPM result in proportional reconstitutions to other types of Blue weapon systems via the force exchange ratios (as do transitions of Blue personnel from the TJ to the CA state). The supportability of the reconstitutions is assumed, but no facts on weapon system replacement or repair capacities are presented.¹¹ If the assumption is invalid, there are not enough shooters to defeat the calculated target pool. Furthermore, because it includes expenditures

⁹In the DG, all ground-launched munitions are classified as LOE munitions. The Army, however, uses a methodology based on two-sided combat simulation, and simulation cannot (should not) be classified as either LOE or threat.

¹⁰The methodology for calculating the requirement for ground-launched air defense munitions, listed in Table 1 as a threat methodology, is identical in structure to the TOLOE methodology once the target pool has been established.

¹¹Reconstitution of weapon systems assumes all nonrepairable kills (K kills) are replaced and all repairable kills (non-K kills) are repaired. For example, cumulative Blue personnel combat casualties of 1.4 MEF (calculated earlier) and a Blue armor to Blue personnel ratio of 1.87/1 (line G of Table 2) results in Blue armor losses equal to 2.6 times the initial deployment. The same arguments apply to the Red target pool. Red may not be able to replace or repair weapon systems fast enough to sustain the estimated force exchange ratios.

by weapon systems that cannot be fielded, the munition requirement is overstated.

THREAT SPLIT

A key issue in calculating munition consumption is how the target pool is distributed over weapon systems. In the TOLOE methodology, targets are allocated by a hierarchical system as shown in Fig. 6. Targets defeated by weapon systems other than the TOLOE weapon systems are removed from the target pool (Level 1 of Fig. 6). Naval surface fire systems,¹² Marine air (fixed wing and rotary), and Navy air are all weapon systems capable of defeating armor, artillery, buildings, command posts, or field fortifications.

Either of two methods could be used for allocating armor targets to Marine and Naval air. The first method is based on the expenditure rates from the Navy's LOE methodology for calculating the requirements for air-to-surface munitions and the number of friendly aircraft associated with the MARCOR-1B scenario. The calculations result in the armor target pool being wiped out by aircraft with no targets remaining for the ground-launched munitions to defeat. Although this method was not used, it suggests the difficulties of allocating targets among weapon systems, classes of weapon systems, services, and allies.

The method used to allocate armor targets to Marine and Naval air is the COSAGE-Marine-posture technique. The percentages of artillery, field fortifications, buildings, and command posts allocated to Marine and Naval air are estimated using Marine professional judgment in light of the armor results and the expected sortie availability.

The next split of the threat is between direct-fire and indirect-fire weapon systems (Level 2 of Fig. 6). The allocation of armor targets between indirect-fire and direct-fire weapon systems is estimated using the COSAGE-Marine-posture technique. The armor threat allocated to indirect-fire weapon systems is increased 20 percent to hedge against uncertainty. This increase results in target overlap.¹³

¹²Naval surface fire systems (used primarily to suppress enemy fire in amphibious assaults) were not allocated any ground targets.

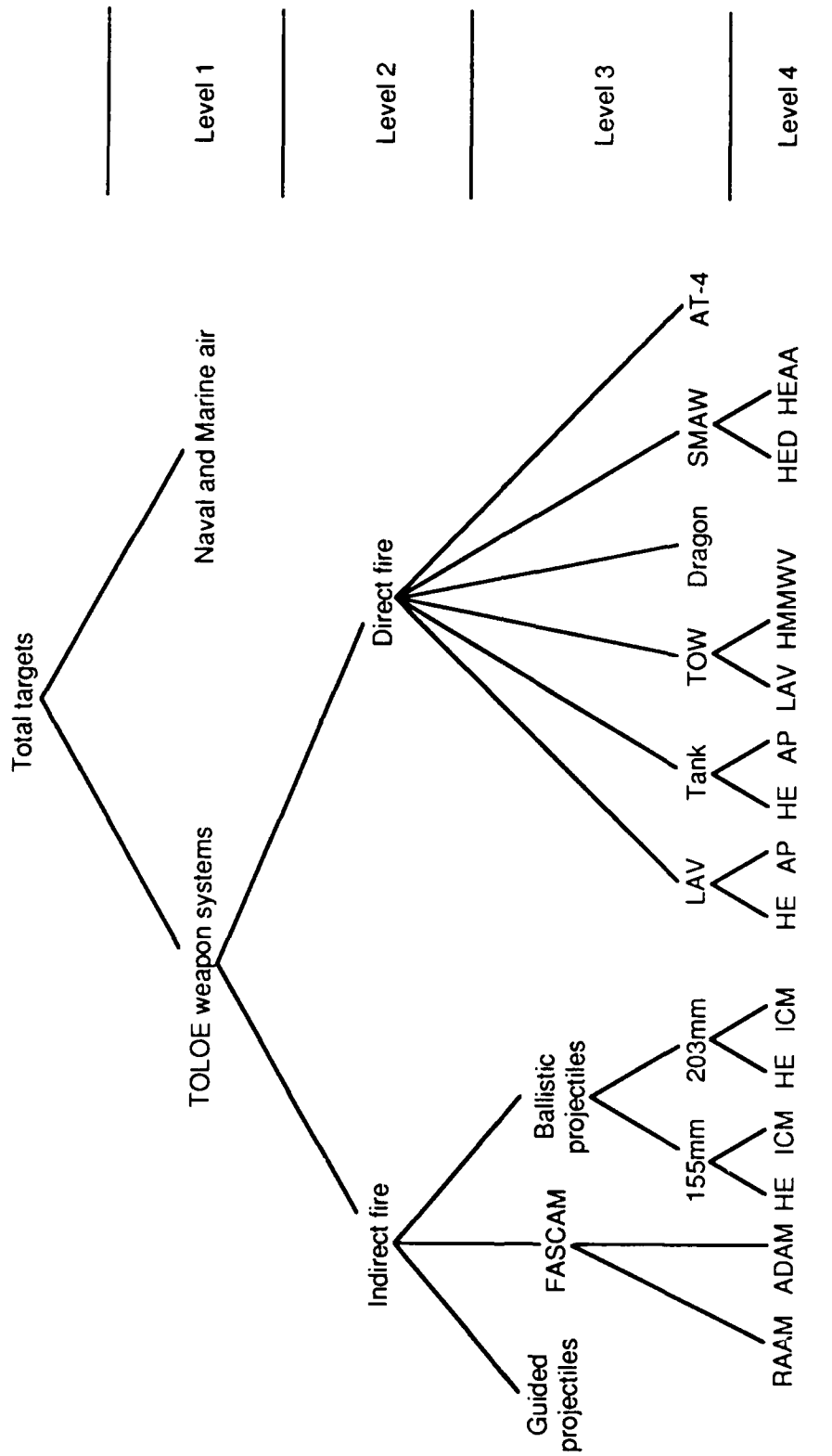


Fig. 6—Allocation of the target pool, repeated for each threat category

For the other threat categories, the allocation between direct-fire and indirect-fire weapon systems is estimated using Marine professional judgment.

Although the COSAGE-Marine-posture technique is used in the more aggregate threat splits (Levels 1 and 2 in Fig. 6), target allocation at lower levels does not rely on Army simulation results. Instead, the target allocations are derived using Marine professional judgment. The resulting allocations differ significantly from those output by COSAGE. In fact, the allocations output from COSAGE vary substantially from study to study (probably why the TOLOE methodology does not use them). This suggests there is considerable uncertainty in allocating targets, particularly as the allocations become more refined.

The allocation of tank and mechanized infantry targets to the direct-fire weapon systems is not established by estimating the percentages directly (Level 3 of Fig. 6). Rather, the relative effectiveness of tanks, LAVs, TOWs, and Dragons are multiplied by the number of weapon systems to determine a weighted system effectiveness for attack and defense postures. The percentage each system contributes to the total weighted effectiveness, averaged over the posture profile, determines the target allocation.

As an example of the above methodology, assume tanks and TOWs are the only weapon systems against a single target category. Tanks are rated twice as effective as TOWs in attack and equally effective in defense. If there are 10 tanks and 20 TOWs, the weighted effectiveness for attack is 20 for tanks and 30 for TOWs. Therefore, in an attack posture, 2/5 of the targets are defeated by tanks and 3/5 by TOW. Similar calculations for defensive postures might result in 1/4 for tanks and 3/4 for TOWs. The target allocation is determined by averaging over the posture profile.

To hedge against uncertainty, the armor target pool is increased by 20 percent (multiplied by 1.2), and the additional targets are allocated to SMAW and AT-4 weapons systems. Because the armor targets allocated

¹³Target overlap occurs when the sum of the targets allocated exceeds the original number of targets in the target pool.

to indirect-fire and direct-fire weapon systems were both increased by 20 percent to hedge against uncertainty, the overall armor target pool to be defeated by ground-launched munitions includes a 20 percent target overlap.

For indirect-fire weapon systems, targets are allocated to the categories of Copperhead, FASCAM, and ballistic projectiles (Level 3 of Fig. 6) based on Marine professional judgment of weapon system effectiveness and the number of tubes. The allocation of targets to ballistic rounds is split between 155mm and 203mm rounds, again, based on subjective estimates of effectiveness and the number of tubes.

The Target Overlap Problem

The TOLOE methodology uses target overlap on several occasions to hedge against uncertainty. (1) The armor target population is increased by 20 percent to hedge against the uncertainty associated with allocating targets to weapon systems. How was the value of 20 percent decided on? (2) The process used in the Navy's LOE methodology to calculate air-to-surface munition requirements results in extreme target overlap (all targets are killed approximately twice). (3) The use of a "worst case" scenario exacerbates the failure of the 1987 Class V(W) study to establish if the target pool calculated (which is substantial when multiplied by the USMC's three active and one reserve MEFs) results in target overlap between Services and allies. So in fact, there may be several institutions establishing munition requirements for the threat the USMC has determined it will defeat.

Although OSD is trying to address the issue of target overlap, because of uncertainty there is no correct value of target overlap (between Services, weapon systems, or any other categories). To correctly address the issue of target overlap, a trade-off must be established between scarce resources (e.g., funds) and risk reduction (e.g., to decrease the probability of running out of inventory when faced with an uncertain demand). Simply increasing a single estimate of the requirement using target overlap does not address the tradeoffs involved and provides no additional information to decisionmakers (see Sec. IV).

For example, the requirements for the USMC's ground-launched and the Navy's air-to-surface munitions result in a target overlap of over 100 percent for armor targets. Neither the USMC or the Navy has a budget sufficient to fund their entire requirement.¹⁴ The actual level of target overlap (if any) from existing inventories is not accounted for by decisionmakers when they allocate resources. The decisionmakers simply try to fill their requirement without regard to the shortfalls in other munition programs (particularly those included in the budgeting process of a different service).

EXPECTED EXPENDITURES

Figure 6 (Level 4) depicts the further allocation of the threat among different munition types.¹⁵ The allocation of targets among the munition types fired from the same weapon system are based on percentages (100 to 0 percent) determined from Army combat simulations or Marine professional judgment.

The expected number of rounds required to kill a target on average, referred to as *rounds to kill*, is equal to $1/pK$. If a threat category (e.g., tanks) includes more than one target type (e.g., T-55 and T-72 tanks), a weighted average of the rounds to kill is used. For example, a pK of 0.1 against T-55s, 0.05 against T-72s, and a target population consisting of 50 T-55s and 100 T-72s implies an average rounds to kill for the threat category of tanks of approximately 17: $([10 \times 50 + 20 \times 100]/150 = 16.7)$.

The rounds to kill for each munition-target combination is estimated using the COSAGE-Marine-posture technique, Joint Munitions Effectiveness Manual (JMEM), Marine professional judgment, or combinations of all three. There is considerable (real world)

¹⁴This is one reason why the TOLOE methodology correctly disregards a scenario in which the armor threat is defeated entirely by surface-to-air munitions when calculating the requirement for ground-launched munitions.

¹⁵The target allocation for TOW is based on equipment type rather than munition type, and Dragon and TOW expend only a single type of munition.

uncertainty associated with the estimates of the expected value of the rounds to kill.¹⁶

A suspect (or false) target factor is used for some direct-fire weapon systems. Suspect targets are treated the same as real targets and require the same number of rounds to kill as real targets. For example, a 30 percent suspect target factor increases the number of targets and the requirement by 30 percent.

THE MARINE THREAT MODEL

The Marine Threat Model is executed to calculate the requirement for each munition-period combination (a single run can accommodate multiple target types). It accommodates the distribution of target kills among periods and adds consumption for the following: (1) rounds needed to supply the initial allowance (IA)¹⁷ for deployed (or redeployed) shooters, (2) rounds required for the resupply reserve (rounds expended in combat), (3) rounds required to achieve a specified statistical confidence level, (4) rounds for zeroing or registration, and (5) rounds to cover logistic losses.

Distribution of Target Kills Over Time

To distribute target kills over time, the scenario is broken up into six 30-day periods. Table 3 is an example of how target kills are distributed over the scenario. The target kills in Table 3 are cumulative over the periods. Hence, 30 tanks are defeated in days 1-30, 30 in days 31-60, 10 in days 61-90, etc. The distribution of target kills is identical to the distribution of Blue combat casualties in the TPM.

¹⁶For example, the munition requirements are calculated for a conflict set in the last year of the POM and, hence, involve force structures at least five years into the future. The threat data rely on imperfect intelligence. Furthermore, it is impossible to estimate or include in field tests the effects of the "fog and friction" of war.

¹⁷The IA (or basic allowance, load out, ammunition initial issue quantity (AIHQ), basic load, full load, etc.) refers to the designed capacity of the equipment to carry ammunition.

Table 3
DISTRIBUTION OF TARGETS OVER TIME
(Total target kills equal 100)

Days	Tanks
1-30	30
1-60	60
1-90	70
1-120	80
1-150	90
1-180	100

Initial Allowance (IA)

The TOLOE methodology uses the time profile of the shooter population to calculate the rounds required for IAs. Initially deployed shooters require an IA. All K kills (irreparably damaged shooters) are assumed replaced in the same period, and the replacements require an IA. Non-K kills (reparable shooters) are assumed repaired in the same period. A percentage of the non-K kills result in the loss of on-board ammunition and require an IA on redeployment. The split between K and non-K kills is estimated using Marine professional judgment.

The attrition of Blue weapon systems is established using force exchange ratios. For example, from line F of Table 2, the overall relative force exchange ratio of percent Blue armor to percent Blue personnel is 1.87/1. If there are 100 tanks initially deployed in an MEF, then 295 tanks are damaged or destroyed in combat.¹⁸ Based on the assumptions above a percentage (e.g., 40 percent) of the damaged or destroyed tanks require an additional IA.¹⁹ From an ammunition planning point of view, 218 ($100 + 0.4 \times 295$) tanks are deployed. Table 4

¹⁸There are also approximately 100 (or as few as the reconstitution level) tanks active at the end of the conflict.

¹⁹The 40 percent represents (1) replacements for destroyed tanks and (2) redeployed (and repaired) damaged tanks that lost their on-board munitions when damaged.

illustrates how the deployment of shooters translates into a demand for munitions. The first period includes the initial deployment of a full MEF. The timing of the IAs for replaced and repaired tanks follows the accumulation of Blue personnel casualties output from the TPM.

Distribution of Targets Across Identical Shooters

For a given munition and period, the expected value of the expenditures is equal to the rounds to kill multiplied by the number of targets summed over the different target types. In the Marine Threat Model, however, the resupply reserve is not equal to the expected value of the expenditures. If the number of targets defeated by a shooter is small, the shooter may kill the targets with munitions from its IA without need for resupply.

The Bose-Einstein distribution, a special case of the Polya distribution, is used to model the distribution of targets among identical shooters (necessary for calculating the reserve size). Historical naval combat data have been successfully modeled using this highly skewed distribution.²⁰ The Bose-Einstein distribution has not

Table 4
CUMULATIVE DEMAND FOR IA ROUNDS

Item	Days					
	1-30	1-60	1-90	1-120	1-150	1-180
Shooters	135	171	183	194	206	218
Rounds (IA=4)	540	684	732	776	824	872

²⁰The distribution of targets among identical shooters could be uniform (e.g., 200 targets and 10 shooters result in 20 targets per shooter). In actual combat, however, some shooters are killed before they can defeat their share (as defined by the uniform distribution) of the threat. Also, in reality, the shooters would not be identical because of the variability in the skills of the people who operate the weapon systems.

been supported by data for modeling ground combat. Its use in the Marine Threat Model is an extension of previous work by a contractor for the Navy.

Table 5 is a tabulation of a target distribution. It gives the number of targets each shooter kills, which is an intermediate calculation needed in determining the number of munitions each shooter expends.

In calculating each shooter's need for resupply, it is necessary to use an explicit resupply policy. In the Marine Threat Model, resupply occurs (instantaneously) when a shooter expends half of its IA.²¹

To determine the number of munitions that each shooter expends, the effect of a pK less than one is combined with the target distribution of Table 5 (a partial example of the results of that combination is shown in Table 6). It is assumed that shooters not killing any targets do not expend any munitions.²² For example, because 50 of the 100 shooters do

Table 5

A BOSE-EINSTEIN TARGET DISTRIBUTION:
100 TARGETS AND 100 SHOOTERS^a

X = number of targets killed	Probability a shooter kills X targets	Number of shooters that kill X targets
0	0.5	50
1	0.25	25
2	0.12	12
3	0.07	7
4	0.03	3
5	0.01	1
6	0.01	1
7	0.01	1

^aTaken from Ref. 3, exhibit 3-31, p. 3-84.

²¹The Marine Threat Model accepts as inputs the IA and refill size, so the policy can be varied. The logistics of transporting the resupply to the shooter, however, is not modeled.

²²As mentioned above, historical naval data support the

Table 6
EFFECT OF PK ON RESUPPLY
(Single shot $pK = 0.5$)

No. of Munitions Expended (R)	No. of Targets Killed (C)				
	0	1	2	3	...
0	50	0	0	0	
1	0	12.5(25x0.5)	0	0	
2	0	6.25(12.5x0.5)	3(12x0.25)	0	
3	0	3.125(6.25x0.5)	3(6x0.5)	0.875(7x0.125)	
4	0	1.5625(3.125x0.5)	2.25(3x0.25+3x0.5)		
.					
.					
.					

not kill any targets, the probability of a shooter expending zero munitions is 0.5. The calculations for the number of shooters that expend R munitions are carried out in a similar fashion.²³

Bose-Einstein distribution for modeling the distribution of *target kills* among identical shooters. It is being used, however, to predict the distribution of *munition expenditures* among identical shooters. Assuming shooters with zero targets kills (real or suspect) do not expend munitions is questionable (numerous counterexamples can be found) and is an anomaly of extending the model from target kills to munition expenditures.

²³The pK of 0.5 implies 12.5 of the 25 shooters that kill one target will successfully defeat their target with one munition. Of the shooters who expend two munitions, 6.25 (12.5 x 0.5) are the result of shooters who kill only one target (6.25 of the 25 shooters who kill one target require two munitions) and 3 (12 x 0.25) kill two targets (three of the 12 shooters that kill two targets do so by expending only two munitions). Of the shooters who expend three munitions, 3.125 (6.25 x 0.5) kill one target (3.125 of the 25 shooters who kill one target require three munitions), 0.875 (7 x 0.125) kill three targets (of the seven shooters who kill three targets 12.5 percent are successful expending only three munitions), and 3 (6 x 0.5) kill two targets (three already killed two targets, three missed twice, and six hit once and missed once, implying of the six with one hit, three will kill their second target on the third shot).

In Table 6, each column is associated with a specific number of target kills and each row is associated with a specific number of munitions expended. The entry at the intersection of any row, R, and any column, C, is the number of shooters who killed C targets with exactly R munitions. The calculations used to derive each entry are given in parentheses next to the entry. The sum over all rows for any column C is the number of shooters who killed exactly C targets, which is taken from Fig. 5. The sum over all columns for any row R is the number of shooters who expended exactly R munitions, which is summarized in Table 7.²⁴

Table 7
DISTRIBUTION OF EXPENDITURES

Munitions expended	Number of shooters
0	50
1	12.5
2	9.3
3	7.1
4	5.3
5	3.9
6	2.9
7	2.3
8	1.7
9	1.2
10	1.0
11	0.7
12	0.5
13	0.4
14	0.3
15	0.2

²⁴The numerous combinations associated with any row of Table 6 quickly lead to an extremely complex accounting problem. Rather than trying to calculate the probabilities by enumerating all the possibilities, it is possible to use the characteristic functions of the underlying distributions to derive the distribution in Table 7.

To determine the resupply reserve from Table 7, an IA of four and a resupply of two are assumed. The number of resupplies is calculated as follows: 37.5 shooters require one resupply (62.5 expend either one or zero munitions and do not require a resupply), 21.1 shooters require a second resupply, 11.9 shooters require a third resupply, 6.7 shooters require a fourth resupply, etc. The total number of refills is 83.4. Two munitions per refill results in 167 munitions required in the resupply reserve. Hence, the requirement is 167 for resupply plus 400 for initial allowance for a total of 567 rounds. The expected number of rounds required to defeat all 100 targets (at $pK = 0.5$) is 200 rounds. Because the resupply reserve is 167 rounds, 33 of the shooters end the conflict with three rounds instead of the full initial allowance of four.²⁵

If the resupply policy were changed to an IA of four and resupply at three (resupply after each munition is expended), then the resupply requirement would be 200 and each shooter would end the conflict with a full initial allowance. In the latter case, the requirement is 200 for resupply plus 400 for initial allowance for a total of 600. For the special case of resupply after each expenditure, the resupply reserve equals the expected expenditures.²⁶

As long as resupply does not occur after each expenditure, the net effect of the Bose-Einstein distribution is to decrease the requirement for the period. The resupply reserve is always less than the expected expenditures and the difference is absorbed as a decrease in the on-board quantities of munitions of the shooters at the end of the

²⁵The Navy also uses the Bose-Einstein distribution to model target distribution among identical shooters. Unlike the USMC, the Navy does not automatically include the IA in the requirement. The Navy sets the IA as either the full storage capacity of a shooter or enough rounds to permit the shooters to defeat any encountered threat to a given confidence level without resupply (without knowing a priori which shooters would encounter more targets), whichever is less. Using the Navy's definition of the IA, the skewness of the Bose-Einstein distribution can result in significant increases in the requirement (IA + resupply) as the confidence level is increased because both the IA and resupply are functions of the confidence level.

²⁶This is the method used by the Army.

period. The magnitude of the difference is a function of the resupply policy (initial allowance and refill size), the number of shooters, the number of targets, and the pK.

The Marine Threat Model is executed for each munition and cumulative time period. That is, the run for the *ith* period includes periods 1 to *i* - 1 (each run starts at time zero). The consumption for the *ith* period is calculated by subtracting the consumption for periods 1 to *i* - 1 from the cumulative consumption for the *ith* period. Table 8 displays the ratio of the resupply reserve to the expected expenditures by period. A ratio of 1.0 implies the resupply reserve is equal to the expected expenditures. As the cumulative expenditures increase, the effect of some shooters having less than a full initial allowance at the end of the period (end of the conflict for period 6) has a decreasing effect on the total requirement.

A much simpler approach to the calculations described in this subsection would be to set the resupply reserve equal to the expected expenditures. Another approach would be to assume each shooter ends the period with XX percent of its initial allowance. Hence, the resupply reserve is equal to the expected expenditures minus $(1 - XX/100)$ times the initial allowance times the number of shooters. The same value of XX would be used for all munition-period combinations. The latter approach has the same effect (and the same amount of historical combat data supporting its use for modeling the *expenditure* of ground-launched munitions) as the Bose-Einstein distribution.

Table 8

RATIO OF THE CUMULATIVE RESERVE TO THE CUMULATIVE EXPENDITURES
BY PERIOD

Munition	Period 1	Period 2	Period 3	Period 4	Period 5	Period 6
A	0.744	0.815	0.837	0.844	0.85	0.853
B	0.897	0.931	0.940	0.943	0.946	0.947
C	0.992	0.995	0.996	0.996	0.997	0.997

The Marine Threat Model does not model the logistics of resupplying the shooters.²⁷ The TOLOE methodology assumes the requirement for munitions will not be constrained by the munitions logistic system. The effect is an assumed logistic system with a capacity greater than the demand and infinite responsiveness (provides munitions instantaneously when the shooter reaches the resupply value).

Treatment of Statistical Uncertainty

The resupply reserve is based on the expected expenditures. Analysis of the variance in the number of rounds required to defeat the targets requires both the expected value and the probability distribution. Munition expenditures are modeled as independent Bernoulli trials with probability of success pK .²⁸ The geometric distribution gives the probability that it will take X rounds to defeat a target. If the probability of killing a target with a single round is pK , the mean number of rounds required to kill the target is $E[X] = 1/pK$ and the variance is $\sigma^2[X] = (1 - pK)/pK^2$. All shooters are identical, all targets are identical, and all events of a shooter defeating a target are assumed independent. Hence, the mean number of expenditures (not resupply) required to kill r targets is r/pK (the sum of the means of each event), and (because each event is considered independent) the variance equals $r(1 - pK)/pK^2$ (the sum of the variances).²⁹

²⁷An assumption, correctly or incorrectly, used by all the Services.

²⁸This model represents a significant simplification. In reality, all shots are not independent because adjustments may be made based on a previous shot. The pK is not constant, but is a function of range, target (or shooter) moving or stationary, target in or out of defilade, and so forth.

²⁹An alternative derivation uses the negative binomial distribution. The negative binomial distribution represents the number of failures encountered in a sequence of independent Bernoulli trials (with probability of success pK at each trial) before the r th success. This results in a random variable with mean $r(1 - pK)/pK$ and variance $r(1 - pK)/pK^2$. Conversion from failures to expenditures is accomplished by adding the r successes to the mean number of failures resulting in a mean of r/pK . Adding a constant value to a random variable does not change the variance.

Knowing the variance, it is possible to calculate the number of rounds required to defeat r targets with an explicit confidence level by using the normal approximation of a series of independent Bernoulli trials.³⁰ To achieve a 99 percent confidence level, it is necessary to add 2.33^{31} standard deviations to the resupply reserve calculated using the Bose-Einstein distribution. For the example above, the calculation is $2.33 \times \sqrt{(100 \times 0.5)/0.5} = 33$. The Bose-Einstein distribution is not used to evaluate whether these additional munitions are supplied from the shooters' IA.

As with target overlap and the reasonable worst case scenario, the TOLOE methodology deals with statistical uncertainty by increasing the (single) estimate of the requirement.³² It is ironic that statistical uncertainty (associated with the simplified model of expenditures) is accounted for at a confidence level of 99 percent, whereas the much more likely possibility of the expected value of the pK being different from the value input to the model (due to real world, not statistical, uncertainty) is not accounted for at all.

Other Additive Factors

In the previous section, false targets were established for the direct-fire weapon systems. For indirect-fire weapon systems, support factors reflect expenditures against combat service support targets and for harassment. These factors are specified as a percentage of the total expenditures against threat targets.

³⁰The normal approximation is derived from the Central Limit Theorem and requires the additional assumption of r large or pK small.

³¹The multiples of the standard deviation (added to the mean) required to achieve a confidence level of YY percent is equal to the point α on the X -axis where the area under the standard normal curve from $-\infty$ to α is equal to $YY/100$.

³²Why include only the effects of the right side tail of the normal distribution? For example, if there are 10 targets to be defeated by a munition with $pK = 0.5$, there is positive probability all the targets can be defeated with less than 20 munitions. Hence, adding the 12th munition to the inventory is of more value than adding the 13th (or 25th). No information on relative effectiveness is supplied to decisionmakers by the current practice of simply increasing a single estimate of the requirement.

Indirect-fire weapon systems expend munitions for registration and direct-fire weapon systems for zeroing. Also, all munition expenditures are increased by a percentage to account for logistic losses.

Output

The output of the threat model is the combat planning factors expressed as the rate of munition consumption, in rounds/tube/day for each munition and period. Because the combat planning factors change from period to period, the requirement can be expressed as a function of time (e.g., more intense combat, and hence, greater munition consumption in the first period of the conflict). The consumption of TOLOE munitions for each period is calculated by multiplying the number of weapon systems in the USMC's three active and one reserve MEFs by the combat planning factors for each period and the number of days in the period (30). The total WR requirement is the sum of the consumption for the six periods.

IV. COMMENTS

This section summarizes comments on the 1987 Class V(W) study. The comments are divided into the categories of methodological, assumptions, and uncertainty. The importance of the categories ranges from least important for methodological to most important for uncertainty.

METHODOLOGICAL

The observations below are primarily descriptive or involve methodological aspects of the 1987 Class V(W) study and should be considered if the USMC adopts or adapts the methodology.

- The ATCAL model can correct for differences in the notional force structures used by the Army in COSAGE and the force structures associated with an MEF (known with some certainty) and an ETD. Because many of the parameters estimated using the COSAGE-Marine-posture technique are a function of force structure (e.g., relative force exchange ratios), the ATCAL correction should be done prior to adjusting the parameters using Marine professional judgment. Establishing parameters based on the results of a division-level combat simulation involving significantly different forces could result in misleading estimates.
- The Blue personnel combat casualty rates are critical inputs for sizing the target pool for the TOLOE weapon systems and are related linearly to the number of targets of each type to be defeated (e.g., if the Blue personnel attrition rate is decreased by one half, the number of targets of each type to be defeated is decreased by one half). The estimates of the rates used by the USMC vary significantly from those used by the Army and should be reexamined (see discussion below on uncertainty). The Blue personnel attrition rates have a minimal effect on the SOLOE munition requirements because of the reconstitution

level. (The reconstitution assumption itself is taken up below.)

- Related to the above, the critical role of the TPM in establishing the magnitude and the time distribution of the requirement in the TOLOE methodology should be reviewed. For example, the estimate of the Blue personnel combat casualty rates, the most critical input to the TPM, determines the assumed ability of the USMC to field and repair major weapon systems (through the Blue armor to Blue personnel force exchange ratios), has a multiplicative relationship with the number of threat weapon systems defeated (see above), and to a large extent (in conjunction with the posture profile) defines the timing of target kills in the conflict. Only individuals intimately familiar with the TOLOE methodology would understand the ripple effects a request to estimate the Blue personnel combat casualty rate would have on the requirements.
- The most analytically sophisticated methods used in the 1987 Class V(W) methodology are the use of the Bose-Einstein distribution to allocate targets among identical shooters and the three-state Markov chain representation of Blue personnel strength in the Troop Population Model (TPM). Although providing the study with more "realistic" or "believable" models, neither method significantly affects the results of either the target or shooter oriented methodologies.

Although the above issues are of some concern, more sophisticated analysis should be directed toward concerns (such as those in the next two categories) that more dramatically affect the mix and/or magnitude of the ammunition requirement (and, hence, the mix of ammunition procured).

ASSUMPTIONS

The assumptions made prior to the execution of the Class V(W) study affect the results of both the target and shooter oriented methodologies.

- All damaged or destroyed equipment is assumed repaired or replaced and personnel losses are assumed replaced at the reconstitution level. The USMC should compare the repair, replace, and reinforcement capacities assumed in the 1987 Class V(W) study to the existing capacities. If the actual capacities are less than those assumed, the requirement for both TOLOE and SOLOE munitions will be overstated.
- The projected consumption rates are calculated without considering the real world constraints on ammunition logistic capacity, budget resources, and production capacities. Similar assumptions are used by each of the Services. Prior to the use of Class V(W) planning factors for procurement, these assumptions should be reviewed. The use of more realistic constraints may result in the procurement of a significantly different mix of munitions.

Numerous examples exist where disconnects between planning and procurement can occur because of the assumptions listed above. For example, it may not be possible over the five-year planning horizon of the POM to satisfy the requirement for a munition because of its cost or limited production capacity (all recently introduced munitions can suffer from this problem to some extent). This could affect the consumption rates of other munitions, particularly those designed to defeat similar targets.

As another example, the assumption of unconstrained ammunition logistics in the requirements process can result in projected consumption rates exceeding the capacity of the ammunition logistic system (because of excessive volume or weight). The firepower of an MEF during the critical early stages of a conflict could be significantly

degraded because the inventory was established without considering logistic constraints.

Although the imposition of constraints is considered to be in the realm of the procurement rather than the requirement process, the principal source of information for procurement decisions is the combat planning factors. The pertinent question is: Would additional information improve ammunition planning and ultimately lead to better procurement decisions? Clearly, checks to ensure the overall system is in balance (e.g., logistics capacities and predicted expenditure rates) can only lead to improvements. To ensure that disconnects do not occur, ammunition planners need more information than is currently provided by the requirements process.

The bureaucratic process for establishing budgets leads to the development of Class V(W) planning factors associated only with the narrow definition of the requirement as being completely unconstrained (as in the assumptions listed above), regardless of how useless the results are for making procurement decisions once the funding is established. The same methodologies, if properly designed, could provide valuable information to decisionmakers by calculating combat planning factors associated with more realistic constraints.

UNCERTAINTY

The following comments deal with the current assumptions, explicit and implicit, on how uncertainty associated with predicting future ammunition consumption rates is dealt with. The problems are not unique to the USMC, or for that matter, to the problem of munition requirements.

- Although the scenario used in the Class V(W) study is not developed in detail (e.g., compared to the Army's WARRAMP study), the threat, intensity, and other attributes result in combat planning factors for a single specific worst case contingency.¹ The USMC, however, must be prepared to engage on

¹The assumption of a worst case scenario may result in an increase

a worldwide basis, suggesting there is considerable uncertainty in the scenario.

- There is considerable uncertainty associated with the most critical input to the SOLOE methodology (expenditures per hour). Prudent planning suggests conservative (reasonable worst case) estimates be used, but this provides little information for allocating resources in a constrained environment.
- There is considerable uncertainty about the allocation of targets to weapon systems in the TOLOE methodology and, hence, the appropriate mix of munitions. Target overlap, which increases the requirement, is used to provide a hedge against the uncertainty.
- The requirement is increased to hedge against the statistical variability to a confidence level of 99 percent.

Increasing a single estimate of the requirement² to hedge against the uncertainties described above does **not** insulate the USMC from the effects of uncertainty unless it is possible to fund the entire requirement. Furthermore, buying out the uncertainty in the form of larger inventories may **not** provide the most robust or cost effective solution to the problem. The current practice (of increasing a single estimate) simplifies the analysis, but it does not provide enough information to decisionmakers. By focusing on a single estimate, ammunition planners increase the risk that large differences could exist between the projected ammunition consumption rates used for planning and procurement and the rates encountered in an actual contingency (possibly with catastrophic results).

in the consumption estimate for some weapon system/round/target combinations whereas others may decrease. For example, a worst case scenario that results in the highest expenditures of anti-armor munitions may result in expenditures of anti-personnel munitions that are lower than those in other scenarios.

²That is, the result is a single estimate of the combat planning factors (consumption rates) for each munition and period.

How would better information regarding uncertainty be used? One example: the munitions requirement process could be used to derive a mean estimate and a standard deviation. This would make it possible to address such questions as: What is the relative variability of consumption among the munitions? A significantly more sophisticated statement of the requirement would take the form of a distribution of possible demands.³ The robustness of buying a mix of ammunition could be defined in terms of the different demands.

A better description of the effects of uncertainty would allow ammunition planners to analyze such questions as: At what point will increased procurement of a munition be simply buying out the consumption associated with a few worst case scenarios, after the procurement already satisfies the consumption associated with most of the scenarios expected? At what point should one continue to buy one type of munition to satisfy the demand associated with a single worst case scenario, while sacrificing (because of budget limitations) the sustainability of another type of munition in several more likely scenarios? There is no single answer to the above questions, because the correct answer depends on which scenario (if any) ultimately occurs. The consideration of such questions, however, would aid in the procurement of a more robust mix of munitions. With the single estimate of the requirement currently provided, the information does not exist to address such questions. The author is working on such a strategy in RAND's Army-sponsored Arroyo Center.

Also, by better describing the uncertainty associated with the demand for munitions, one could better investigate alternatives to buying larger inventories. If highly variable demands are predicted for a munition, is it desirable to invest in large inventories? Other than investing in larger inventories, investment options could include a responsive and flexible production base.

³The concept of a distribution of demands in the discrete case suggests multiple estimates of the demand and a weighting factor associated with each of the demands.

None of the inputs associated with the TOLOE and SOLOE methodologies used in a Class V(W) study are known with certainty. The uncertainty and sensitivity of the munition requirement to some inputs are greater than others; such inputs will be referred to as *critical inputs*. The critical inputs for SOLOE munitions are the posture profile and the daily expenditure rate for each posture. The critical inputs for TOLOE munitions are the number of targets of each type to be defeated, the allocation of targets to munitions, the rounds to kill, and the posture profile.

To address the uncertainty associated with the critical inputs, a fast and responsive methodology should be developed. The simplifications suggested in this Note (for the removal of the Bose-Einstein distribution and the three-state Markov chain) would allow the TOLOE and SOLOE methodologies to be implemented on a spread sheet (or similar highly aggregate model). With simpler models, munition planners could quickly address uncertainty by varying the values of the critical inputs. The "worst case" requirement for a particular munition will always be associated with the greatest of the alternative demands (the most pessimistic values of the critical inputs for that munition). Calculating alternative demands would allow decisionmakers to include the concept of the robustness of the inventory into procurement decisions.

Improper treatment of uncertainty is in no way unique to the USMC; it is shared by all the Services. Because the Services' munitions budgets have been underfunded, the munition acquisition processes (the two-step process of establishing the requirement and then enforcing budget and production constraints) have been particularly ill-served by suppressing the effects of uncertainty from decisionmakers. Although the Services are not entirely to blame for the improper treatment of uncertainty,⁴ they are not prohibited from developing methodologies capable of generating alternative demands and providing this information to the decisionmakers who make procurement decisions.

⁴The need for a single (correct?) estimate of munition consumption is driven by the budget process and has been institutionalized in the guidance handed down to the services by OSD.

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